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DEVIATE PROPORTIONAL NAVIGATION.(U)

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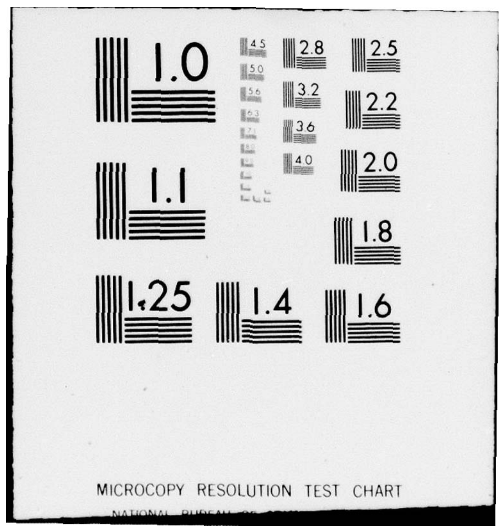
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TECHNICAL REPORT T-79-46

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DEVIATE PROPORTIONAL NAVIGATION

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9 April 1979

Redstone Arsenal, Alabama 35809

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A variation of proportional navigation in which the attitude or approach direction at intercept is also controlled is described. Additional sensors are not required but additional on-board computation is required. The derivation is based upon an optimal intercept law.

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CONTENTS

1. INTRODUCTION

"Deviate: To turn aside from a course; to stray, as from a standard."

For decades, proportional navigation has been the standard against which other intercept guidances laws have been compared. For certain applications it is also desirable to control the body attitude at intercept. For example, an anti-tank missile may be more effective against the top of a tank since the sides are designed to withstand kinetic energy rounds. Also, it is desirable to loft the trajectory of anti-radiation missiles (ARM's) to reduce dispersion at impact and to extend the range.

One possible approach would be to incorporate the attitude angle in the state of the system and place cost upon that angle at the terminal time and then optimize, using modern control theory.[1,2]

The approach in the following is to use an optimal intercept law,[3,4] and the attitude at intercept is implicit in the choice of the coordinate system. The intercept law was previously found useful in developing an alternative derivation of "lead bias" proportional navigation.[5]

1. M. Kim and K.V. Grider, "Terminal Guidance for Impact Attitude Angle Constrained Flight Trajectories", IEEE AES Vol. 9, No. 6, November 1973, pp. 852-859.

2. R. J. York and H. L. Pastrick, "Optimal Terminal Guidance with Constraints at Final Time", Journal of Spacecraft and Rockets, Vol. 14, No. 6, June 1977, pp. 381-383.

3. A. E. Bryson, Jr., "Linear Feedback Solutions for Minimum Effort Interception, Rendezevous and Soft Landing," AIAA Journal, Vol. 3, No. 8, August 1965, pp. 1542-1544.

4. R.E. Dickson and V. Garber, "Optimum Rendezevous, Intercept and Injection," AIAA Journal, Vol. 7, No. 7, July 1969, pp. 1402-1403.

5. R. E. Dickson, Optimum Intercept Laws and Lead Bias Proportional Navigation (U), US Army Missile Command RD-TR-70-14 (AD-510 828), July 1970 (Confidential).

2. OPTIMAL INTERCEPT AND DEVIATE PROPORTIONAL NAVIGATION

An optimal intercept control law which was previously studied[4] is

$$u(t) = \frac{-3\, x(t_f,t)}{(t_f-t)^2}\,, \tag{1}$$

where

$$x(t_f,t) = \sum_{n=0}^{\infty} \overset{(n)}{x}(t)\,(t_f-t)^n/n! \tag{2}$$

is the (predicted) miss at the final time, t_f, assuming no (further) control. Only the first two terms of the Taylor series, Equation (2), will be considered here

$$x(t_f,t) \cong x(t) + \dot{x}(t)\,(t_f-t). \tag{3}$$

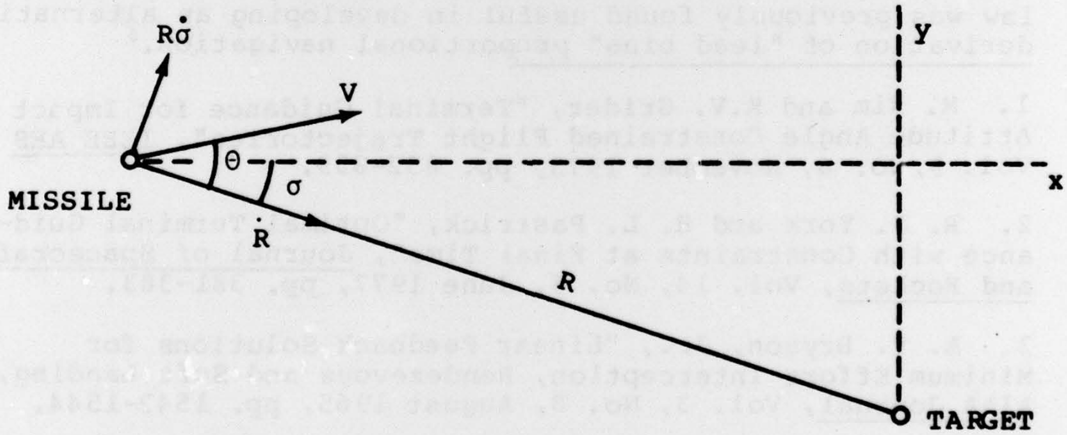

Figure 1. Relative rotating coordinates.

From Figure 1

$$x = -R\cos\sigma \tag{4}$$

$$y = R\sin\sigma \tag{5}$$

$$\dot{x} = \dot{R}\cos\sigma + R\,\dot{\sigma}\sin\sigma \tag{6}$$

$$\dot{y} = R\,\dot{\sigma}\cos\sigma - \dot{R}\sin\sigma\,. \tag{7}$$

It follows from Equation (3) that

$$x(t_f,t) \cong -R\cos\sigma + (\dot{R}\cos\sigma + R\dot{\sigma}\sin\sigma)(t_f-t) \quad (8)$$

and

$$y(t_f,t) \cong R\sin\sigma + (R\dot{\sigma}\cos\dot{\sigma} - \dot{R}\sin\sigma)(t_f-t) \quad (9)$$

Setting

$$x(t_f,t) = 0, \quad (10)$$

it follows that the time to go is

$$(t_f-t) \cong \frac{R\cos\sigma}{\dot{R}\cos\sigma + R\dot{\sigma}\sin\sigma}. \quad (11)$$

Then the control u(t), is along the y-axis,

$$u(t) = \frac{-3y(t_f,t)}{(t_f-t)^2} \quad (12)$$

$$\cong -3\left\{\frac{y(t) + \dot{y}(t)\,(t_f-t)}{(t_f-t)^2}\right\} \quad (13)$$

$$\cong -3\left[\frac{R\sin\sigma}{\left\{\dfrac{R\cos\sigma}{\dot{R}\cos\sigma + R\dot{\sigma}\sin\sigma}\right\}^2} + \frac{R\dot{\sigma}\cos\sigma - \dot{R}\sin\sigma}{\left\{\dfrac{R\cos\sigma}{\dot{R}\cos\sigma + R\dot{\sigma}\sin\sigma}\right\}}\right] \quad (14)$$

and, after some manipulation,

$$\cong -3\,(\dot{R} + R\dot{\sigma}\tan\dot{\sigma})\ \dot{\sigma}/\cos\sigma, \quad (15)$$

or, factoring out an $\dot{R}$,

$$\cong -3\dot{R}\dot{\sigma}\,(1 + \tan\theta\tan\sigma)/\cos\sigma. \quad (16)$$

Near a collision course, small angles may be neglected and Equation (16) may be simplified to

$$u(t) \simeq -3\,\dot{R}\,\dot{\sigma}, \tag{17}$$

proportional navigation!

Retaining small angles, Equation (15) becomes

$$u(t) \cong -\;3(\dot{R}\,\dot{\sigma} + R\,\dot{\sigma}^2\,\sigma), \tag{18}$$

and Equation (16) becomes

$$u(t) \cong -3\,(\,1 + \theta\cdot\sigma)\,\dot{R}\,\dot{\sigma}, \tag{19}$$

or

$$u(t) \cong -3\left[\,1 + \left(\frac{R}{\dot{R}}\right)\;\dot{\sigma}\,\sigma\right]\;\dot{R}\,\dot{\sigma}. \tag{20}$$

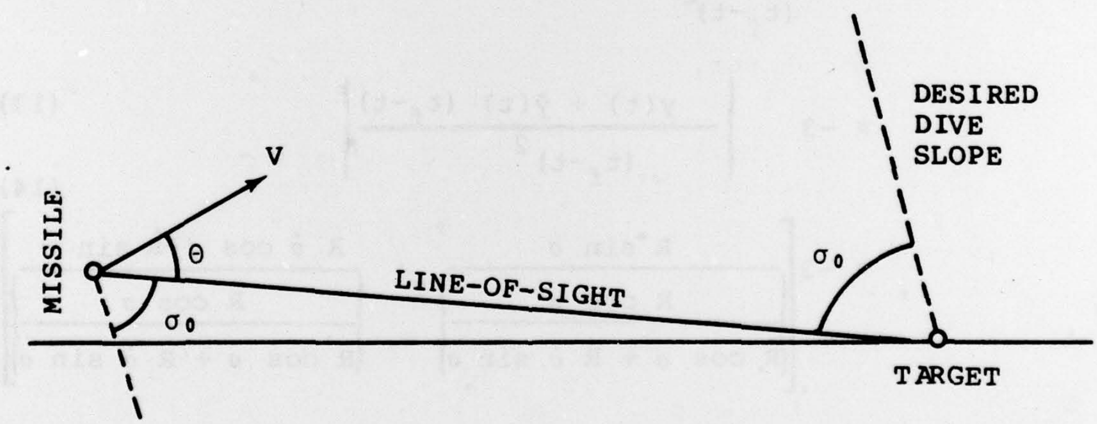

Figure 2. Deviate proportional navigation.

In Figure 2, the line-of-sight (LOS) angle, σ, is chosen initially to be negative; the dive slope is the x-axis. The effect of a negative line-of-sight angle, σ_O, and positive theta, Θ, in Equations (18), (19) and (20) is to reduce the "gain" until the missile is in the vicinity of the desired

dive slope. The line-of-sight angle, σ, is usually referenced to the horizontal as in Figure 1, but this is not necessary nor may it be desirable when the effects of the small angles, Θ and σ, are included.

Measurement of the relative range, R, is generally not practical and Equation (18) will be eliminated from further consideration. The addition of an angle of attack sensor would allow determination of theta, θ, assuming that the effects of the velocity of the target and the winds are insignificant, but this sensor could interfere with the LOS rate, $\dot{\sigma}$, sensor.

This leaves Equation (20). The signal received by the LOS rate sensor is proportional to the range,

$$e = \frac{J}{R^n} . \tag{21}$$

Taking the log of both sides of Equation (21),

$$\ln e = \ln J - n \ln R \tag{22}$$

and then differentiating,

$$\frac{\dot{e}}{e} = \frac{\dot{J}}{J} - n\left(\frac{\dot{R}}{R}\right) . \tag{23}$$

Assuming that

$$\dot{J} = 0, \tag{24}$$

$$\frac{R}{\dot{R}} = - n\left(\frac{e}{\dot{e}}\right) , \tag{25}$$

as required in Equation (20). For a point source an inverse square law would be appropriate, i.e.,

$$n = 2. \tag{26}$$

Under these assumptions and assuming that the closing rate, $\dot{R}$, is known approximately, no additional sensors are needed but additional on-board computation is required (see Figure 3).

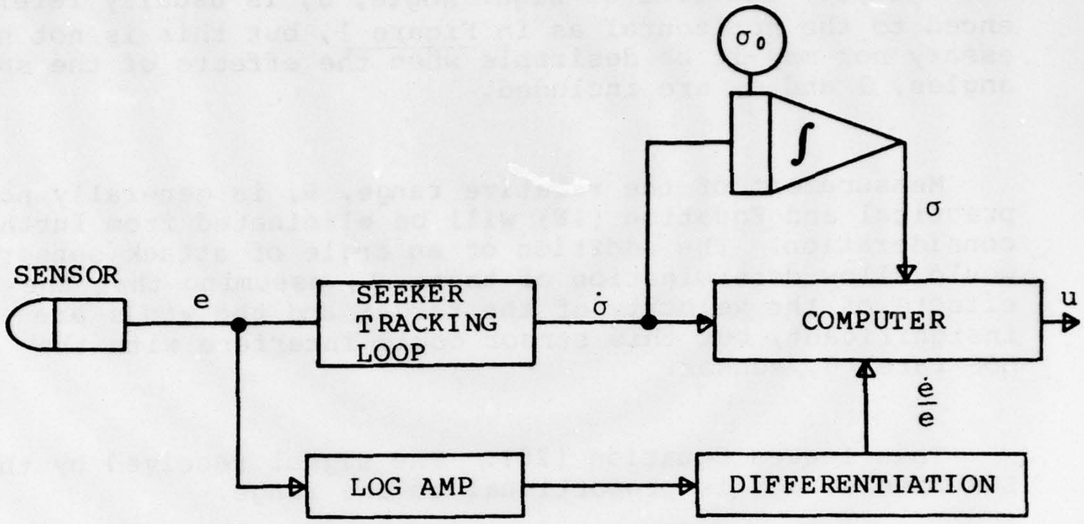

Figure 3. DPN implementation.

Of course, the launch condition, θ, and the initial condition on the integrator, σ_O, must be chosen so as to achieve the desired dive slope at intercept.

It would seem that the initial condition on the integrator, σ_O, could have a fixed value and that theta, θ, would be tailored to the launch conditions of the particular flight, i.e., the range and altitude at launch.

Implementation might be further simplified by assuming that $(R/\dot{R})$ is Equation (20) is a constant.

3. CONCLUSIONS

Since deviate proportional navigation (DPN) reduces to proportional navigation (PN) in the vicinity of the desired dive slope, there would be no advantage in implementing Equations (15) or (16).

The assumptions which were made would not appear critical in the "end game". With microelectronics the additional "on-board" computation required does not appear to be the problem it would have been in the past.

Since the purpose of this report is to close the loop, feedback is welcomed. The name "devious" proportional navigation has already been suggested.

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